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RESEARCH ARTICLE

Effect of an Intervention Based on Multisensory Environment for Proprioception Assessment in Children With Down Syndrome: Case Study

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ABSTRACT A Multisensory Environment (MSE) is a tool that can be used to train and stimulate the vestibular and proprioceptive systems of users, and engage them in therapeutic activities through sensors. This manuscript aims to verify the effects of an intervention protocol with MSE through a game platform to train proprioception in children with Down syndrome (CwDS). This pilot study was carried out using a system designed with the specific purpose to evaluate the children's functional performance through data acquired using a system based on an RGB-D camera arrangement. The children underwent a physiotherapeutic intervention protocol of 12 sessions of game therapy, with 30 minutes duration each and a frequency of one session per week. This protocol was implemented to analyze the movements of three CwDS (mean of nine years old at the beginning of experiments). The CwDS evaluated in this research had an average proprioception score established by a Psychomotor profile test of (m=10.43) before the beginning of the intervention, showing deficient and dyspraxic profiles among the children. After the application of our MSE, the final score of this test showed an average of (m=16.44) indicating a Typical development (TD) profile for all the children.

INDEX TERMS Serious games, virtual environment, children with down syndrome, RGB-D cameras, motor development, assistive devices.

I. INTRODUCTION

The presence of all or a portion of an extra copy of chromosome 21 (HSA21) [4] causes Down syndrome (DS), with a frequency of 1 in 750 live births, to be the most common non-inherited cause of cognitive deficiency, and is also one of the most common causes of learning difficulties [32]. The syndrome is associated with a variety of medical and health-related issues [29], including dynamic motor dysfunction, which causes agonist and antagonist muscle pairs

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to contract simultaneously, as well as balance and postural issues [18], [30]. These deficiencies, which are noticeable in these children, may be directly related to missed motor development milestones [36]. In fact, because of generalized muscle hypotonia and ligament laxity that are traits of DS, newborns and people with DS experience delayed motor development [33].

Although the neuropathological cause of motor dysfunction in DS is unknown, proprioceptive and vestibular abnormalities, delayed myelination, and cerebellar dysfunction have all been suggested as potential causes [19], [41]. Early physical therapy has centered on promoting motor control and coordination to fulfill developmental goals in the first few years of life [40]. Rarely do children who have begun walking (which is frequently delayed by an average of 12–18 months) continue to get physiotherapy [35]. But multiple reports in the literature indicate that children with DS start having orthopedic issues in their early years and would benefit from specialized biomechanical evaluation and care [11], [27], [40].

A sensory dysfunction, or the improper processing and integration of sensory stimuli, is regarded to be the root cause of the majority of DS-related deficits [26]. A skewed or incomplete version of this process leads to the development of an aberrant mental image of the outside world. As a result, this can result in physical impairments, deficits in cognitive abilities like generalization, space awareness, language usage, and social behavior [12], [29], as well as distress and discomfort, frequent concentration lapses, and disengagement from the suggested tasks [13], [33], [45]. According to the notion of sensory integration, planning and organizing behavior is made up of sensory components and is constructed by the proprioceptive sense [5], [34].

The ability to perceive one's body and its parts spatially is known as proprioception [25]. Children with DS (CwDS) frequently exhibit proprioception deficits. Therefore, without the right stimuli, proprioception gains in CwDS are very minimal and sluggish. However, it is accepted that strong assistance from a young age might enhance CwDS talents [32]. Although certain treatments have been created, they are not universally applicable since they need to be highly personalized and continually modified to meet the demands of CwDS [5]. With the help of exercises that foster gross and fine motor coordination, attentiveness, and social interaction, for example, many therapy procedures aim to teach the CwDS certain fundamental skills so they can develop autonomy in their everyday lives [18], [22], [44].

A Multisensory Environment (MSE) is a room designed to stimulate the user's vestibular and proprioceptive systems, train the integration and recognition of various stimuli, and engage the user, through sensors, in beneficial activities [43]. The way MSEs are applied can have an impact on results, according to diverse researches [15], [23]. A previous study has shown that an MSE may help autistic youngsters with their sensory functioning, according to data from a small-scale descriptive study ($n = 6$) that involved only six participants [31]. However, to yet, no study has delved into the specifics of how to employ the MSE to support advantages for CwDS.

However, new trends in assistive technology-based tools utilized in multimodal therapies are using various types of stimuli because of technical advancements in therapeutic interventions [17], [42]. Serious games may employ multisensory interventions based on RGB-D multi cameras as one method of movement analysis [38]. For instance, it has been shown that a setting with tools that record the user's movements along with serious games that confirm their accuracy might enhance the perception of an acceptable stimulus [46]. However, to effectively meet the needs of the user, it is vital to understand their functionalities and requirements [8].

The fundamental benefit of a game-based system in a sensorized environment is its capability to give physicians control over the features of the virtual environment (VE) while adjusting the level of difficulty to meet specific user needs [43]. In line with that, this research suggests a game-based approach using an MSE for CwDS using automated analysis of bodily movements with RGB-D cameras. The intervention system is put into place in accordance with a tried-and-true methodology to objectively elicit cognitive and proprioceptive skills, in addition to the practical needs and demands voiced by psychologists and physical therapists. The device is suggested as an addition to conventional therapies, supporting specialists in the field to produce objective metrics for analysis during physical training and rehabilitation.

The main contributions of this paper are: (i) the development of a MSE environment to perform an automated analysis of body movement estimation using a real-time system based on a noninvasive vision sensor network. (ii) a game structure to improve motor skills and proprioception, and (iii) the implementation of an assessment protocol with a virtual environment for CwDS.

II. MULTISENSORY ENVIRONMENT ARCHITECTURE

This study is based on an evaluation system that demonstrated the value of motor analysis and the need for a system that is specifically targeted at children with Down syndrome [43]. That assessment system demonstrated the value of an intervention tool delivered in an immersive setting, which was required to create a MSE with a game-based platform.

A. AUTOMATED CHILD'S MOVEMENT ANALYSIS

A depth-cameras configuration with two RGB-D cameras (Microsoft Kinect v2) was built together with an approach for angle correction, as suggested in a previous work [42]. This computational vision system, which was designed to automatically estimate the joint position of CwDS during their movements, is made up of an unstructured and scalable network of RGB-D sensors. The system can recognize body gestures and gather certain information, including the three-dimensional positions of each body articulation and its range of motion.

Figure 1 shows the MSE, which is made up of two connected modules (ROS and Windows OS). The first one uses redundant sensor monitoring (Clients 1 and 2) to automate the study of a child's movement, and it is built as a distributed, modular workstation network utilizing the open-source Robot Operating System (ROS).[1] Utilizing the primary ROS design requirements, the node graph technique (server and clients) was used to construct the ROS-based system process. This system is made up of a few nodes for local video processing and a web application bridge that are dispersed across a number of different hosts and connected in real time via a peer-to-peer topology.

The XML-RPC protocol uses a handshake to represent the internode connection. The node structure is adaptable, expandable, and changeable on the go. Both the multi-camera network calibration tool offered by OpenPTrack and the OpenCV package are used to calibrate each RGB-D camera intrinsically and extrinsically. The Microsoft.NET Framework, which is Just-in-Time (JIT) created, is used by the Unity game engine in the second module to create game scenes. The fused joint data is received and used as input in the gaming environment via the UDP protocol. The spatial relationship between the child's movements and the position of the targets is calculated to create interaction in the game-based platform, as explained in Section II-B.

B. GAME-BASED PLATFORM

Utilizing Unity, the game-based system is constructed in five hierarchical tiers. The user interacts with the system using input and output devices (RGB-D cameras, display (projection), and speakers, as depicted in Figure 2). The application programming interfaces (APIs) of the device are under the control of the loop in the game-based system, which reads and uses the users' joint estimation. Through the created games, this data is used to handle visual interaction. The user's movement parameters are collected and saved for later study.

Figure 3a illustrates how a special room was set up to support the system needs. The child is placed in the center of the RGB-D cameras and in front of the display projection at the start of the experiment. The measuring equipment then records the child's joint position parameters, which are needed to provide the data specified by the VE. With the use of these data, the game platform provides the child with feedback, and the evaluator (a therapist) can use them to calculate quantitative values as part of a kinematic evaluation protocol. Figure 3a shows therapist helping the youngster and encouraging his or her proper motions for a particular game while they are both inside the room, out of the cameras' field of view. The game-platform operator is hidden behind a window with a one-way mirror in the room, manipulating the game's features while secretly watching the child's activity.

[1]Robot Operating System (ROS) - http://www.ros.org

According to the features of the game and the stimulus it provides to the child, the VE can be set up in one of two modes. As shows in Figure3b, the first arrangement is made for a selection of games that need the child to engage frontally with visual cues projected on the wall. The second configuration, shown in Figure3c, projects the game onto the ground, increasing engagement and simulating touchscreen functionality.

The game-platform implemented has three different games: "Left-Right", "The Catcher" [38], and "Whack-a-Mole" [38]. The system starts to save movement data when the game starts, storing the tridimensional location of fifteen body joints. The platform saves the movements throughout the course of each game. For posterior analysis, each file has a unique identification number. The suggested games were developed based on a series of activities that can identify functional psychomotor features connected to the child's learning potential, including sensory and perceptual integration.

1) THE LEFT-RIGHT GAME

This game evaluates the children's laterality skills while giving them visual feedback akin to a mirror. A voice command specifies which object or side the children must select, such as "select the star on the right side," "select the balloon on the left side." To choose the right object on the right side, the kid must move his or her hand or foot (Figure 4a), utilizing the corresponding limb for each side. A point is awarded if the child chooses the right side and the right limb. A voice instruction prompts the youngster to switch to the proper limb if the incorrect one is being utilized. To help the child to choose the correct side, there are a variety of visual stimuli in the game.

The stimuli include right and left hand drawings in each side as well as colored "right" and "left" identification marks, distinct colors for each side, different objects to be selected, and a blink behind the object that should be selected. As shown in the video on the link[2], the idea is that the youngster would connect those pictures and hues with the appropriate side, acting as a guide.

2) THE CATCHER GAME

As shown in Figure 4.b, it depicts a squirrel avatar as overseeing gathering various types of food (such as fruits, sweets, pizza, etc.) that are randomly falling from the top of the screen. In this game, the player uses his or her own body to control the game character. The link[3] displays an illustration of a player engaging in game play.

3) WHACK-A-MOLE GAME

The projector is pointed at the ground in this interactive game. The fundamental idea behind this setup is to enable touch interaction between the kid and things that are projected on

[2]https://youtu.be/e9LvZQ5ibBQ
[3]https://youtu.be/tVF1HsX8JSE

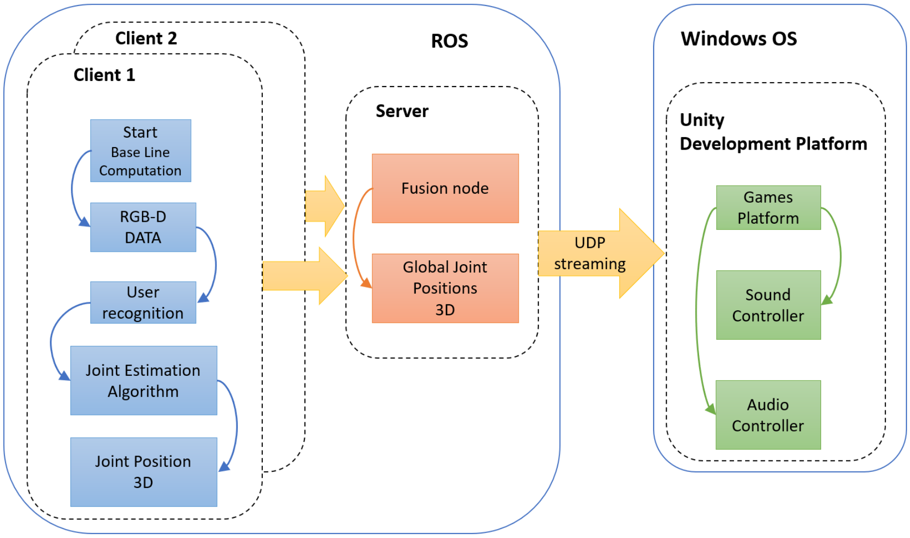

FIGURE 1. System architecture of the multisensory environment (MSE).

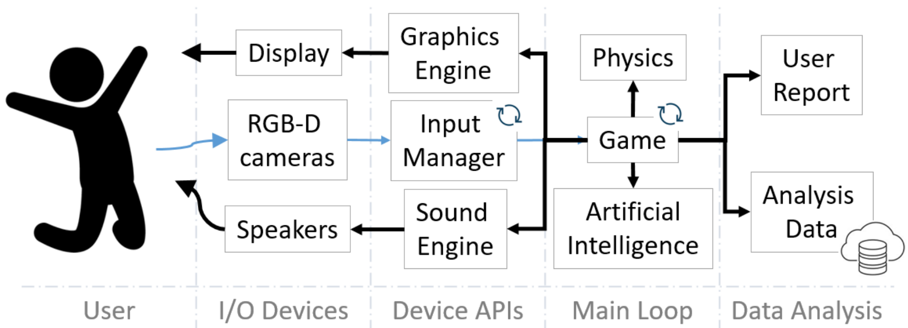

FIGURE 2. User's interaction with the game-based system.

the floor. As shown in Figure 4.c, the graphical user interface of the game shows six holes and a mole that comes out of one of them. To earn points, the young player must literally foot on the target while walking or jumping on the mole. The link[4] displays an illustration of a player engaging in game play.

III. CASE STUDY

Through a serious game protocol consisting of twelve sessions, one session each week, and lasting around 30 min each, three CwDS were examined to improve their proprioception. Throughout the intervention, the physical therapist assists each child and gives them verbal orders on a regular basis. In this protocol, the three games: Left-Right, Whack-a-Mole, and The Catcher were always played in that order. Each of them lasted for one minute and had three rounds of play. Before the start of each game, the physical therapist instructs and shows the child how to use it properly.

In the first and last sessions, an anamnesis was conducted with the parents of the children. The Berg Scale was used to assess the children's bodily balance during physical therapy [6]. In addition, the Psychomotor Profile Test was used in the first and last sessions to assess proprioception, muscular tone, and motor abilities (fine and gross) (PPT) [16].

[4]https://youtu.be/nOa-db3IlAA

A. CHILDREN'S ABILITIES IN THE MULTISENSORY ENVIRONMENT

The proposed abilities evaluation is as follows:

i) Proprioception. It is the ability to sense stimuli arising within the body regarding position, motion and equilibrium [47]. Through proprioception it is possible to know, for in stance if an arm is above the head or hanging by the side of the body.

ii) Left/Right discrimination. It is possible to improve the ability (speed and accuracy) to discriminate between left and right body parts and movements [9].

iii) Gross motor skills. Are larger movements an individual makes with his/her arms, legs, feet, or entire body, and are fundamental to perform everyday functions, such as walking, running, and are also crucial for self- care operations like dressing [18].

The Psychomotor Profile Test (PPT) methods were used to assess the various activities [16]. The PPT reveals the psychoneurological underpinnings of the modules or elements

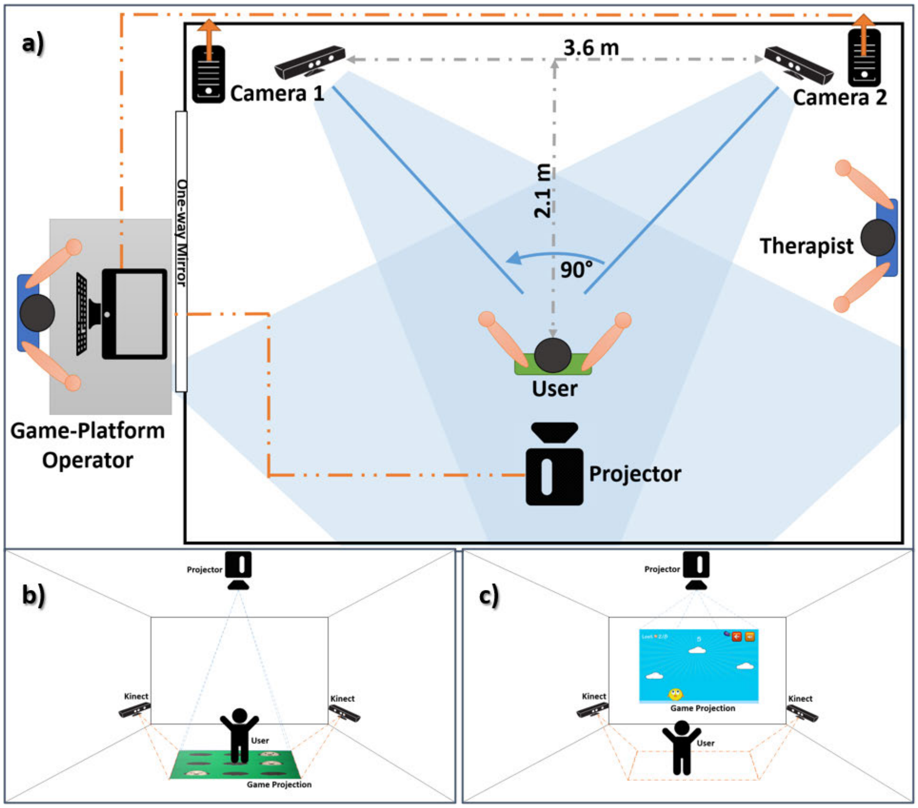

FIGURE 3. Room setup implemented to the multisensory environment. a) Subjects and elements involved position on room. b) Game environment configured for projection on the wall. c) Game environment configured for projection on the floor.

TABLE 1. Numerical rating description for the sum of all factors of the "Psychomotor Observation Manual" [16].

Score range	Psychomotor profile
27-28	Superior
22-26	Good
14-21	Typical Development (TD)
9-13	Dispraxic
7-8	Deficient

TABLE 2. Numerical rating description for the Berg balance scale.

Score range	Description
45 or more	The individual is less likely to fall, safe ambulator without an aid device
Among 35 to 44	The individual has a slightly increased risk of fall, safe ambulator with an aid device
34 or less	Individual with a greater risk of falls, but may be able to ambulate with an aid device and a partner for safety concerns

of psychomotor tonicity, balance, laterality, body awareness, spatiotemporal structuring, and fine praxis. Each element logs the child's replies as a behaviorally defined numerical rating (between 1 and 4). The Psychomotor Observation Manual [16] requires summing all variables, with a minimum score of 7 (one point for each factor) and a maximum score of 28 (4 points per factor). Table 1 displays an explanation of the rating following the total.

The Pediatric Balance Scale (Berg Scale) [6], which assesses the child's balance in fourteen settings that are typical of daily activities, was used to measure the children's physical and dynamic body balance at the same time. The maximum score that can be earned is 56 points, and each item has an ordinal scale of five possibilities that range in difficulty from 0 to 4 points. Table 2 displays a description of the rating following the total.

B. PARTICIPANTS OF VIRTUAL ENVIRONMENT INTERVENTION

Children with a clinical diagnosis of DS, aged 7 to 12 years, who were identified as having a deficient or dyspraxic psychomotor profile on the PPT and who scored lower than 44 on the Berg Scale met the inclusion criteria for this study. Other neurological changes, concomitant respiratory or osteomyoarticular diseases, or the inability to comprehend and follow straightforward vocal orders are all exclusion factors. Parents or legal guardians gave their approval for their children to participate in the study by signing an informed consent form, which was authorized by the UFES/Brazil Ethics Committee (number 1.629.376).

The sample for this case study is composed of two female children and a male child (9.66 ± 0.69 years, at the beginning of the experiments), with clinical diagnosis of DS (simple and

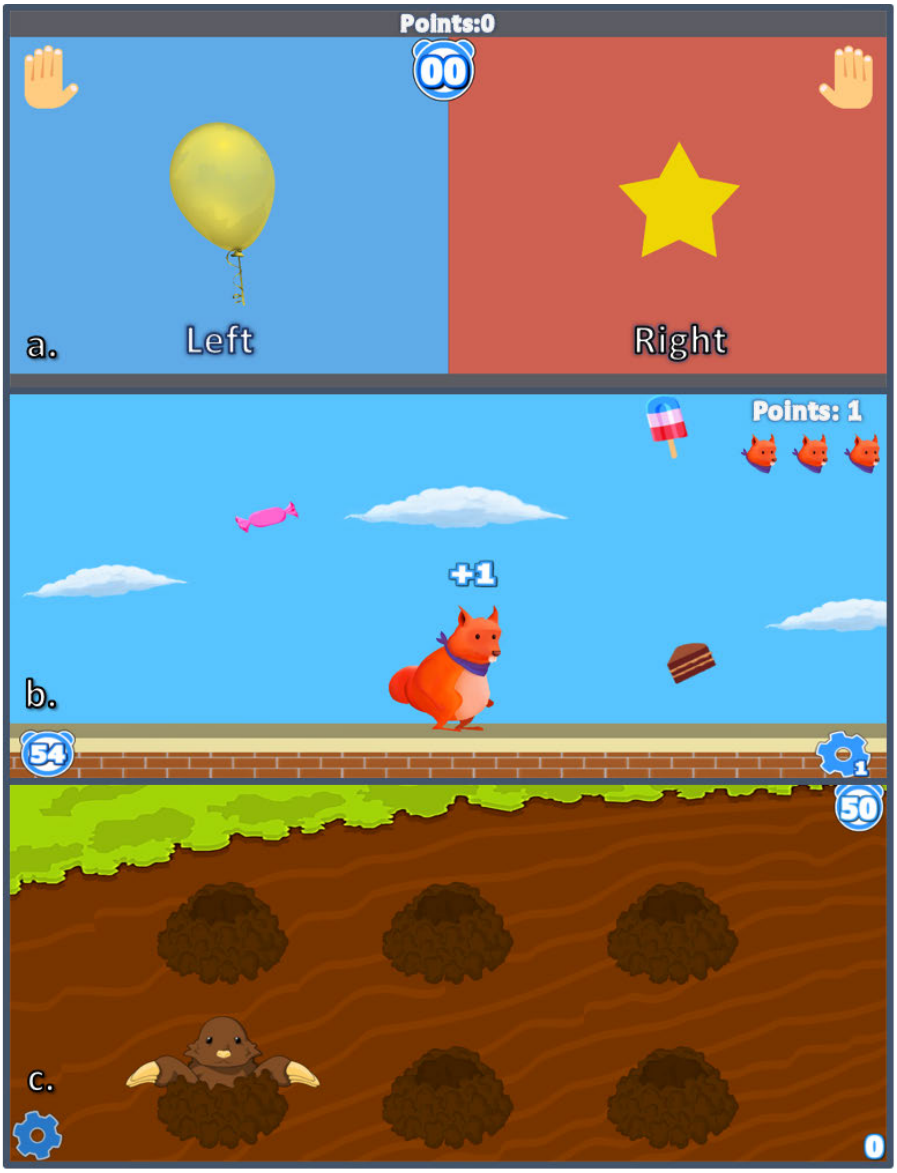

FIGURE 4. Games-platform implemented. a) Left-Right game environment for hands movements; b) The Catcher game environment [38]; c) Whack-a-Mole game environment [38].

mosaic trisomy of chromosome 21) and associated hypothyroidism, with some episodes of fall, presenting a deficit psychomotor profile. The anamnesis of each child is shown in Table 3.

IV. RESULTS

Two distinct analyses are shown in the next sections. Starting out, a game-based evaluation was used to gauge each child's performance and make comparisons between the first and last sessions. The psychomotor profile of each child is presented in the second section, along with a comparison of their motor behavior before and after the 12 intervention sessions.

A. GAME PLATFORM ANALYSIS

To understand the child's performance through the game-therapy sessions and find improvement after the intervention, specific movements and a related analysis were determined, as presented in Table 4.

1) LEFT-RIGHT GAME FOR HANDS

Hand-hip distance, and the shoulder angle of each child is taken as a reference in this game. The first child presented problems with laterality in the first session of the game, as shown in Figure 5.a. In this figure, it is possible to see the target required for the game, as boxes in the base of the Figure (blue indicates left, and red indicates right). Likewise, the response of the child is shown, where the first child had 5 successes and 4 failures. The game starts by "raising the left hand" (blue box at the base of the figure), an action that is not performed; on the contrary, the child raises the wrong hand and then corrects it for the requested one and so on, presenting a constant interaction.

TABLE 3. **Anamnesis of participants (children).**

Child	1	2	3
Initial of Name	A	J	L
Genre	Male	Female	Female
Age (years)	8	9	10
Dominant side	Right	Right	Right
DS Associated pathologies	Hypothyroidism	Hypothyroidism	Hypothyroidism
Medicines	Levotiroxina 12.5 mcg Respiridona 0.5 mg	Levotiroxina 38 mg Montelucaste 0.5 mg	Puran T4 25 mg Trofanil 25 mg
Observations	Moderately severe hearing loss and use of hearing aid	–	Uses glasses for astigmatism correction (2.5º in each eye)

TABLE 4. **Movement analysis performed for each game.**

Game	Movements	Analysis
Left-Right for Hands	Put the hand upward the shoulder	Hand-hip distance
		Abduction-adduction shoulder angle
Left-Right for Feet	Put one foot in front of the other	Foot-center of gravity distance
The Catcher	The child moves around the room	Center of gravity position
	Trunk inclination	Lumbar flexion-extension angle
Whack-a-Mole	The child moves around the room	Center of gravity position
	Trunk inclination	Lumbar flexion-extension angle
	The angular change at knees	Knees flexion-extension angle

The movements made in the same game, but after 12 sessions, can be seen in Figure 5.b., where the child perfectly executes the requirements of the game, performing 10 hits and 0 failures, showing a notable improvement in the understanding of laterality.

The sum of three repetitions of games was taken for each session to analyze the improvement of each child with the Left-Right game for the hands. Progress during all sessions of children 1, 2, and 3 is shown in Figure 6, where the line indicates the child's behavioral trend and each color-point the proportional amount of variation in each session. Comparing the first and last sessions, it was noticed that all children showed an increase in lateralization in the upper limbs, where children 1, 2 and 3 had an improvement rate of 49.63%, 87%, and 59.34%, respectively, as shown in Table 5. The improvement rates were calculated comparing the final values with starting values.

2) LEFT-RIGHT GAME FOR FEET

In this case, the child responds to the command "put the right/left foot in front". If the answer is correct, the next

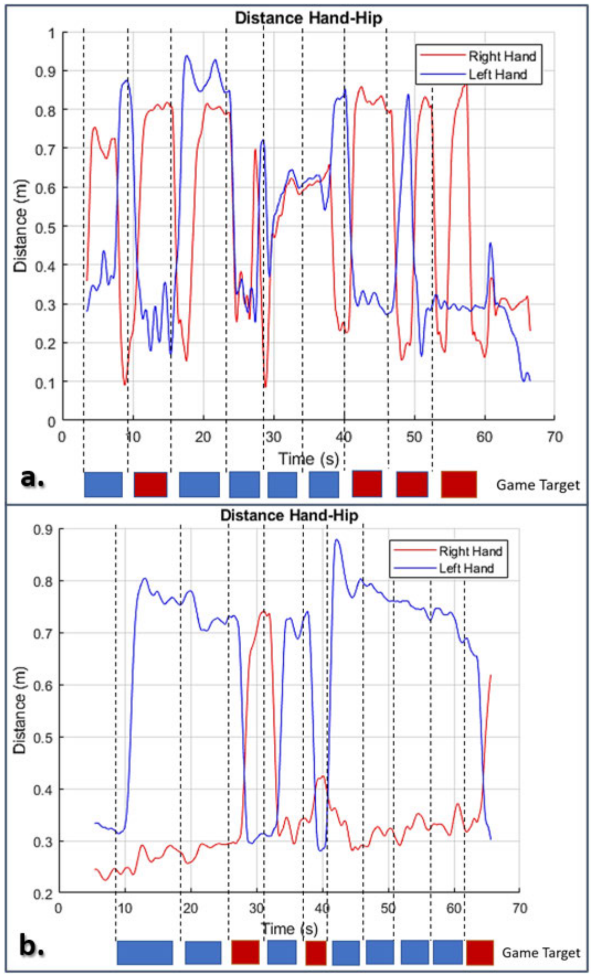

FIGURE 5. **Hand movements performed by Child 1 during Left-Right game. a) First session. b) Last Session.**

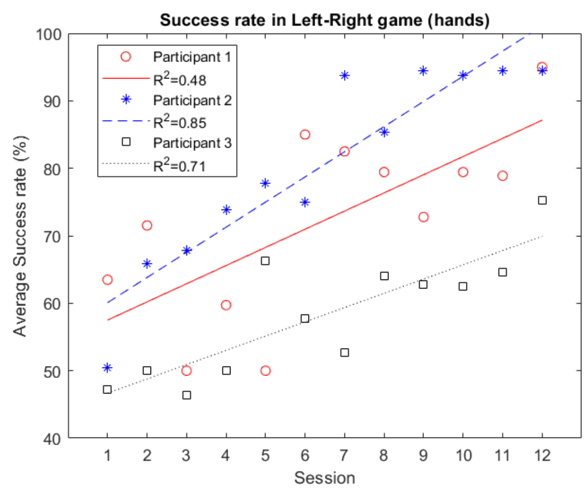

FIGURE 6. **Children progress during the intervention with the Left-Right game for hands.**

command is to "put your feet together", otherwise the game will repeat the command until the child executes it correctly.

Figure 7.a shows the movement of the feet, comparing the distance between each foot and the center of gravity during

the first session, performed by the child 2. In the last session, it can be observed just one mistake in the movements required by the game, achieving a notable improvement in its laterality, as shown in Figure 7.b.

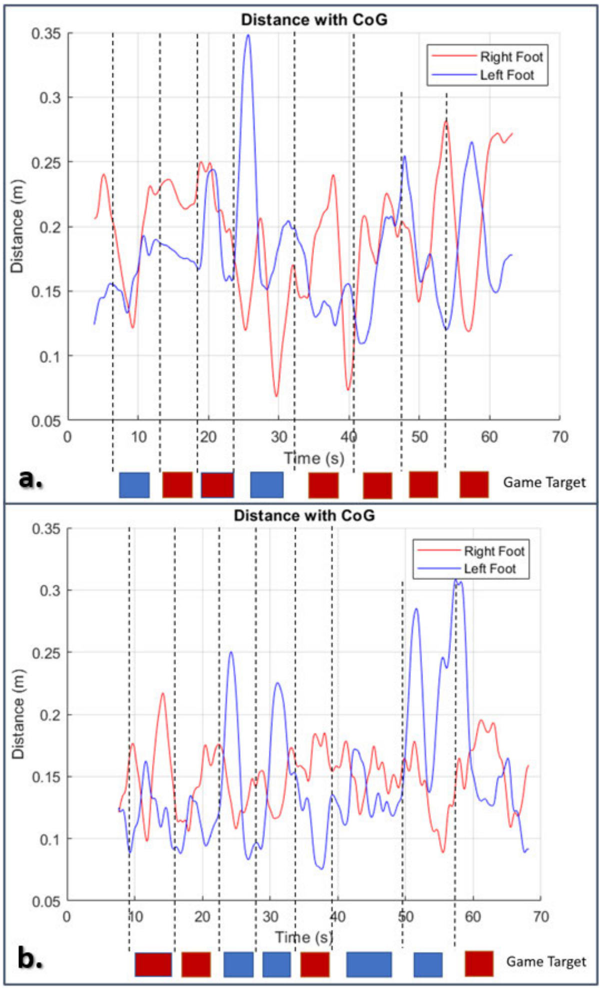

FIGURE 7. Feet movements performed by Child 2 during Left-Right game. a) First session. b) Last session.

Progress during all sessions of children 1, 2, and 3 is shown in Figure 8, respectively, where the line indicates the trend of the child's behavior and R2 the proportional amount of variation in each session. Comparing the first and last sessions, it can be affirmed that all children showed an increase in lateralization in lower limbs, in which children 1, 2 and 3 had an improvement rate of 20.63%, 45.30%, and 35.64%, respectively, as shown in Table 5.

3) THE CATCHER GAME

It allows the child to control the movements of the game character with his/her own body displacement. Due to the children's cognitive and motor characteristics, the game was set to be played with a slow drop rate of food.

Figure 9 shows the trunk inclination. In the first session, the child tried to achieve the objectives of the game without moving around the room, though there was a bending of

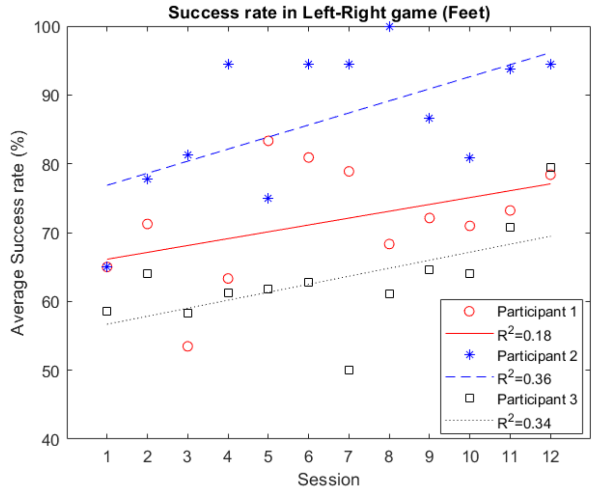

FIGURE 8. Children progress during the intervention with the Left-Right game for feet.

the trunk to control the avatar, arising fall risks as shown in Figure 9.a. In the last session it is possible to observe that the inclination of the trunk is much lower, since the control of the avatar was carried out with the lateral displacement through the room, as shown in Figure 9.b.

To understand the improvement of each child with the game The Catcher, the sum of successes of three repetitions during each session was measured. Progress during all sessions for children 1, 2 and 3 is shown in Figure 10. From the first to the last session, all children showed an increase in their understanding of the game and gross motor skills. Children 1, 2 and 3 had a rate of improvement of 366.67%, 121.21%, and 44.44%, respectively, as shown in Table 5. This table shows the number of points earned (food captured) during the game, comparing the first and last sessions for all children.

4) WHACK-A-MOLE GAME

If the youngster does not pass it over, it will only display one mole at a time for a maximum of 7.5 s. The angular amplitude (range of motion) in the knees used to step on the moles is examined to determine how much improvement has been made while playing this game. Figure 11 depicts the variations in the child's foot placement on the moles before and after the intervention. By analyzing the angular range in the knees, it is easy to detect that the youngster engaged in significantly greater activity in the last session than in the first.

To analyze the improvement of each child with the Whack-a-Mole game, the sum of successes of three repetitions during each session was measured. The progress during all sessions of children 1, 2 and 3 can be observed in Figure 12. The skill improvements are explained with the result shown in Table 5, showing that the child 1 stepped on 31 moles in the first session of the game, and in the last session stepped on 59, an increase of 90.32% in the performance. These results show an improvement for child's capabilities. The same table

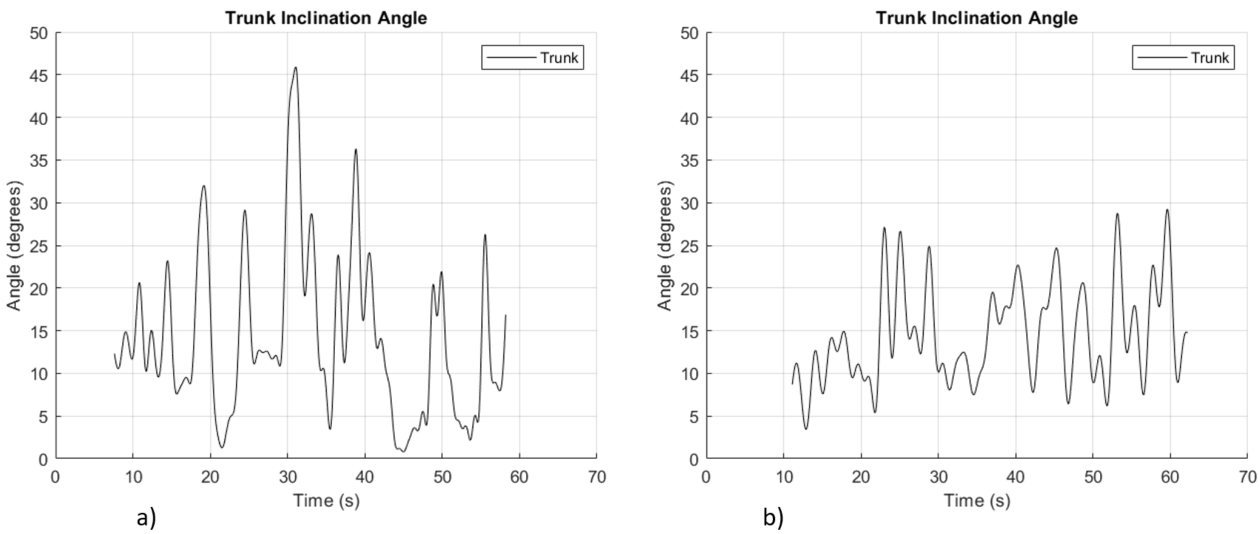

FIGURE 9. Trunk inclination during The Catcher game of Child 2. a) First session. b) Last session.

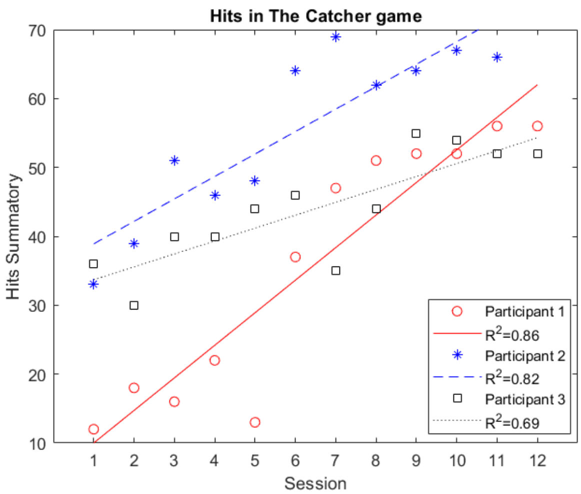

FIGURE 10. Children progress during the intervention with The Catcher game.

TABLE 5. Comparison between first and last session in the game platform for all children.

Game	User	Session	Success	Improvement rate
Left Right Hands	Child 1	First	63.49%	49.63%
		Last	95%	
	Child 2	First	50.51%	87%
		Last	94.44%	
	Child 3	First	47.22%	59.34%
		Last	72.25%	
Left Right Feet	Child 1	First	65%	20.63%
		Last	78.41%	
	Child 2	First	65%	45.30%
		Last	94.44%	
	Child 3	First	58.57%	35.64%
		Last	79.44%	
The Catcher	Child 1	First	12	366.67%
		Last	56	
	Child 2	First	33	121.21%
		Last	73	
	Child 3	First	36	44.44%
		Last	52	
Whack-a-Mole	Child 1	First	31	90.32%
		Last	59	
	Child 2	First	41	60.98%
		Last	66	
	Child 3	First	42	33.33%
		Last	56	

shows the results for children 2 and 3, whose increase was 60.98% and 33.33%, respectively.

B. PSYCHOMOTOR PROFILE ANALYSIS

As shown in Section III, two physical evaluations were conducted on the children, in the first and last session of the intervention, using two different tools. Results of PPT by Fonseca are shown in Table 6 (See Table 1 for Psychomotor profile definitions). Otherwise, the results found through the Berg scale are shown in Table 7 (See Table 2 for Score range definitions).

TABLE 6. Results of Fonseca psychomotor test before and after application of the game therapy protocol.

Child	Test	Average Score	Psychomotor Profile
1	Initial	11.03	Dispraxic
	Final	16.34	TD
2	Initial	11.78	Dispraxic
	Final	18.1	TD
3	Initial	8.48	Deficient
	Final	14.88	TD

V. DISCUSSION AND REMARKS

According to the overall findings, children average scores increased from the first to the last session, indicating an improvement in their proprioception and motor behavior.

This multimodal system was put into place to meet the demands of the clinical community and become a potent

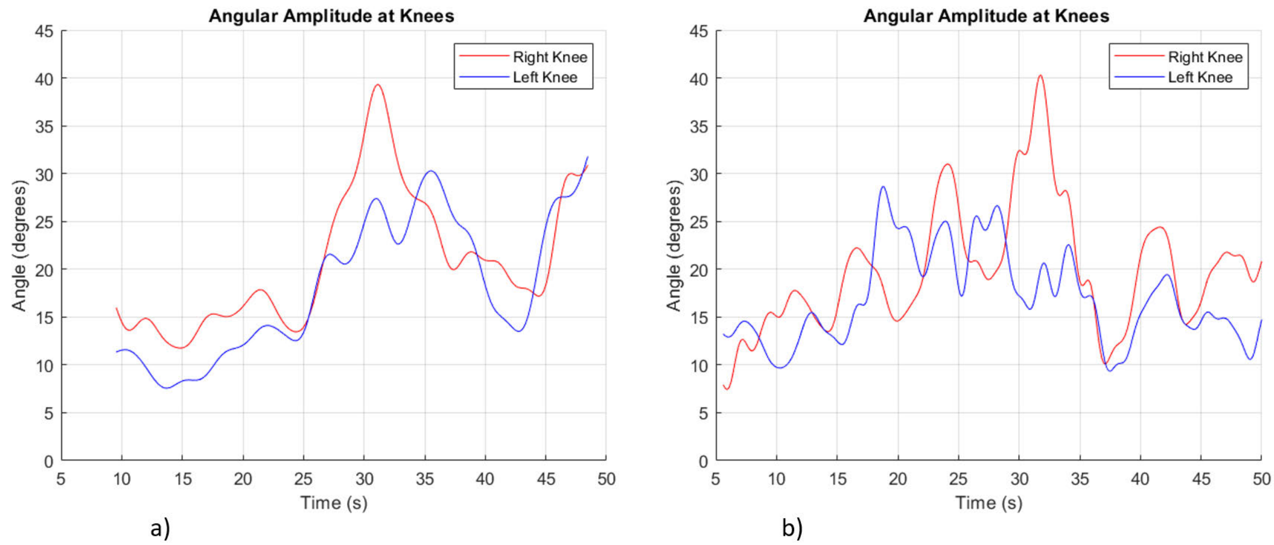

FIGURE 11. Angular amplitude at knees during the Whack-a-Mole game, performed by Child 3. a) First session. b) Last session.

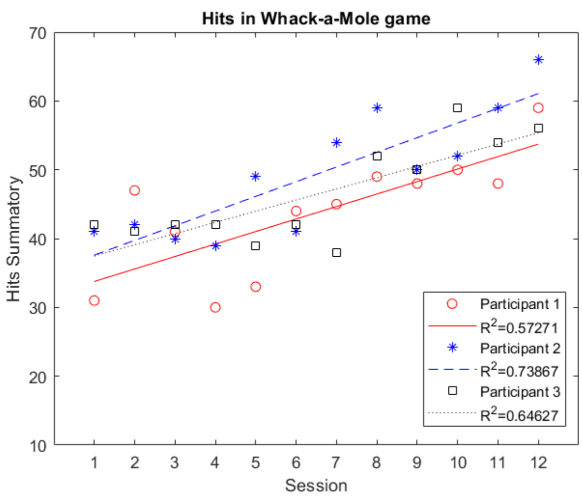

FIGURE 12. Children progress during the intervention with the Whack-a-Mole game.

TABLE 7. Results of Berg Scale test before and after application of the game therapy protocol.

Child	Test	Score	Indication for walking aid
1	Initial	45	No
	Final	51	No
2	Initial	46	No
	Final	51	No
3	Initial	37	Yes
	Final	46	No

tool, as others have done, for obtaining objective criteria for the examination of CwDS motions [10], [20], [28]. With the help of the suggested multisensory system's results, it is possible to demonstrate how all essential tasks completed by the kids and the related kinematic parameters collected by the platform can be examined to gain further medical data for training, therapies, and diagnostics.

The game platform is flexible and appropriate for each child's development. The platform can be used by the health-care expert to assess the children performance and decide whether to raise or lower the level of difficulty. Based on advice from the clinical team, the system can similarly challenge their static and dynamic postural control during the training.

When requiring movements of the lateral body parts, the Left-Right game promotes laterality identification and stimulates postural balance. The upper body game that was used produced the most useful results, with child 2 improving from a success rate of about 50% to 100% of correctly identifying left from right. With the game geared toward lower limbs, the child (2) demonstrated the best improvement rate in the outcomes (45.30 %). It is crucial to emphasize how all children made equal growth in their upper and lower limbs (Table 5), demonstrating an improvement in proprioception and a connection to cognition [14], [21].

In requiring corporal displacement in the transverse axis, the Catcher game stimulated postural equilibrium. An important aspect was that the youngster had to make movements while ignoring the floor and concentrating on the screen projection. All the children showed an intriguing rate of development in the game score, with child 2 displaying the largest improvement (121.21%), and child 1 and 3 having improvement rates of 51.35% and 44.44%, respectively. The gathered information demonstrated how the children motions in the space expanded from one session to the next, increasing their velocity and body balance [1], [24], [39].

The Whack-a-Mole game stimulated movement perception and improved body balance when asking the child to step on the mole that appeared randomly in each burrow. The children played this game with haptic controls and interact with it more actively than they did during the previous session, demonstrating that they comprehended how the game works. The knee angular amplitude, which displays much higher variation in all children throughout the final stages of the intervention, was another important metric sensed. It is important emphasize that other studies demonstrated various exercises using commercial video games with important outcomes for task efficacy and attentional selection, but without movement identification and proprioceptive analysis [10], [28], [37].

The PPT that Fonseca implemented is a sign of certain psychomotor learning capacities or limitations. Prior to the start of the intervention, the CwDS examined in this study had an average proprioception score determined by PPT of (m=10.43), indicating deficient and dyspraxic profiles among the children. The average end score was (m=16.44), which suggests a typical profile for all the kids. A margin of error must be taken into account in the data collection produced by the expert who conducted the assessment, though, as this was a unblinded study. This result supports several studies that demonstrate these children's development has improved, showing that a CwDS can acquire proprioceptive abilities using a tool of this kind [3], [7], [20], [39].

It is important to comment that different child characteristics, such as surroundings, familiarity, mood, and physics may alter the outcomes of therapies or sessions (see Table 3). About The Catcher game, when child 1 did not demonstrate movement throughout the first five sessions, his specific auditory circumstance may interfere with the learning of various tasks.

VI. CONCLUSION

In this pilot study, an analysis of an MSE-based intervention for CwDS proprioception assessment was conducted. We can infer from this study's findings that the developed system and the CwDS's therapy regimen significantly improved the CwDS's specific motor and balance behavior indicators. The games needed the CwDS to move with significant amplitude in both the upper and lower limbs, necessitating also the utilization of trunk movements to produce jumps and weight transfers. The children motor skills were stretched throughout this virtual world engagement, which also helped them with balance and cognitive abilities. The findings demonstrate that our multisensory environment (MSE) can be utilized to induce visual feedback in order to create conflicts between visual, somatosensory, and vestibular information in order to educate different sensory systems, as is also addressed by various types of research [1], [2], [17], [22].

The data given in this study support the use of MSEs as a potentially useful tool to be introduced into CwDS training processes to enhance their motor development and body balancing abilities or related impairments, allowing them to mature in a more independent manner.

The positive findings from this initial evaluation are serving as motivation for further validations, which will involve more participants in subsequent treatments. It is important to note that the limited sample size used to create the intervention made it difficult to produce a statistical analysis of the data. Additionally, the absence of controls and blinding are two crucial issues that must be fixed in future research. This factor makes it impossible to draw any definitive conclusions from the findings.

The creation of various games and interactions must continue to produce a widespread tool and broaden the reach of the MSE. For instance, children with various disorders, dysfunctions, and syndromes may benefit from smart toys and robots that can enhance their motor behavior and cognition.

The system is a cutting-edge tool for producing objective data to evaluate and record, and may be valuable for future therapies and training of health professionals. It can also be utilized by children with different illnesses or cognitive disabilities. The created system can also be employed with ideas like telemedicine and generic medical care.

The next step of this research is to undertake additional trials with CwDS based on the advice of the clinical team, including a new set of various serious games to excite their various abilities.

AUTHOR DISCLOSURE STATEMENT

The authors declare that there is no conflict of interest regarding the publication of this work.

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